Reverberation, Sediment Acoustics, and Targets-in-the-Environment

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LONG-TERM GOALS

Develop and experimentally test target scattering models as well as reverberation/sediment-acoustic models. Quantitatively assess the modeling approximations possible within the fidelity/speed requirements of Navy performance estimators/simulators.

OBJECTIVES

Over at least the last few decades, much of the basic research effort related to ASW has focused on low-frequency propagation (the passive problem). Meanwhile, submarine technology has forced the Navy to increase its use of (low and mid-frequency) active sonar, in which case reverberation (including clutter) limits performance. Contemporaneously, active sonar MCM efforts have extended their frequencies of operation from high down to mid-frequencies. Again, in many cases, reverberation limits performance for these MCM systems. Thus the shallow water problem of acoustic scattering from a target in a waveguide, as well as character of the associated reverberation, continues to be both an applied and basic research problem of some significance over a broad range of frequencies.

My objectives are to:

1) carry out field measurements of shallow water reverberation and target scattering in the mid-to-high frequency range,

2) quantitatively predict these experimental results using a combination of exact finite element modeling, approximate numerical modeling, and analytical physical acoustics modeling.

3) determine the approximations possible within performance-prediction/mission-planning requirements.

APPROACH

The foundation of the reverberation and target scattering research are experiments planned for FY13-14. These experiments involve measurements of target and sediment backscattering as well as

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reverberation. The main experiment will occur off the coast of Florida in FY13 at a shallow water, sand bottom site. A second, more target oriented experiment will occur in FY14 in a shallow water, muddy site. A major goal of the experiments is to measure both the acoustics and the environmental conditions needed as input to models designed to predict the acoustic results. (These experiments are made possible by leveraging a combination of funds from the ONR Ocean Engineering, ONR Ocean Acoustics and SERDP Munitions Response teams.)

Reverberation

Wave theory, ray and energy transport based models of shallow water propagation and reverberation will be compared to the experimental data. The acoustic and contemporaneous environmental measurements will focus on supporting quantitative data/model comparisons in the 3-4 kHz range but will include data taken from 1-10 kHz.

Targets-in-the-environment response (TIER)

The target scattering experiments will cover the frequency range from about 1 to 50 kHz. A variety of targets, to be specified by the sponsors, will be placed in view of a rail/tower system that takes data at a sufficient resolution to produce synthetic aperture images of the target or, alternatively, to develop images of the target strength as a function of frequency and angle of observation. Finite element models (in combination with various physical acoustics based approximations) of the elastic response of these targets will be developed and compared to the data.

Sediment Acoustics

This effort is more model-focused with the corresponding experimental data already in hand from previous ONR work, i.e., SAX99 and SAX04. Data, from those experiments, on sediment sound speed, attenuation and scattering have indicated deficiencies in current sediment models at both low (below 3 kHz) and high (above 150 kHz) frequencies. The approach here will be to examine two physical effects that to this point have not been introduced into the model. At low frequencies this involves the thermal conductivity of the media and at high frequencies its non-continuum nature. This effort will initially take a back seat to the experimental preparations needed to address the first two avenues of research.

WORK COMPLETED

Reverberation

Field-tested (during GULFEX12) the combined operation of the APL-UW sources and the HAARI and FORA receive arrays deployed horizontally about 2 meters above the bottom. The source levels allowed for reverberation results out to 7.5 km. A Navy standard energy transport model (ASPM) has been compared to data from the HAARI array and predictions for wind speed dependence have been made using this same model.

Targets-in-the-environment response (TIER)

APL/UW and NSWC PCD personnel integrated NSWC PCD sources and receiver into the rail/tower system, this integration was tested as part of the GULFEX12 experiment using 21 m length rail. Another 21 m of rail has been constructed so that, during TREX13, a 42 m rail will be deployed. This will allow examination of TIER out to several water depths

Finite element modeling (FEM) results have been compared to experimental results from the PONDEX09 and PONDEX10 experiments. Finite Element developments have allowed model/data comparisons for targets partially buried in sediments at an oblique angle, a condition we previously have felt might be problematic given the FEM modeling technique. A physical acoustics model was developed to understand the effects seen in both data and FEM near broadside for the obliquely buried case. Also, a fast modeling technique developed previously [1] was used to examine TIER as a function of closed loop path orientation and radius (mimicking AUV operational concepts). The technique allows a speed up of about 10,000 relative to full FEM with little loss of fidelity and allows insight into the physics of the changes seen as a function of AUV operational parameters.

Sediment Acoustics

A 30-year perspective of the developments of sand acoustics was presented at the OA2012 conference in Beijing and a proceedings paper written [2]. The effort involved in summarizing the progress in the last 30 years allowed identification of current limitations to our collective knowledge.

RESULTS

Reverberation

The left panel of Fig. 1 shows the ASPM 6.3 prediction of reverberation at 1 kHz using the bathymetry in the region of GULFEX12. ASPM forward loss models at 1.5 kHz and above are known to be in error so 1 kHz was used to allow the actual measured sediment parameters to be used in the model. The center panel shows the experimental results derived from HAARI array measurements. The right panel shows the topography of the area (centered on the ship) with a black box indicating the area corresponding to the other two panels. Note that the effects of the bathymetry show up clearly in both data and model. Detailed comparisons of the model to data indicate a faster reduction of reverberation with range in the data than in the model. This may in part be due to the difference in frequency used but also is due in part to the Lambert scattering approximation (arguably of high enough fidelity for some tasks, e. g., in mission planning tools such as ASPECT used by NAVAIR) inherent in ASPM that is at odds with the known physics of backscattering.

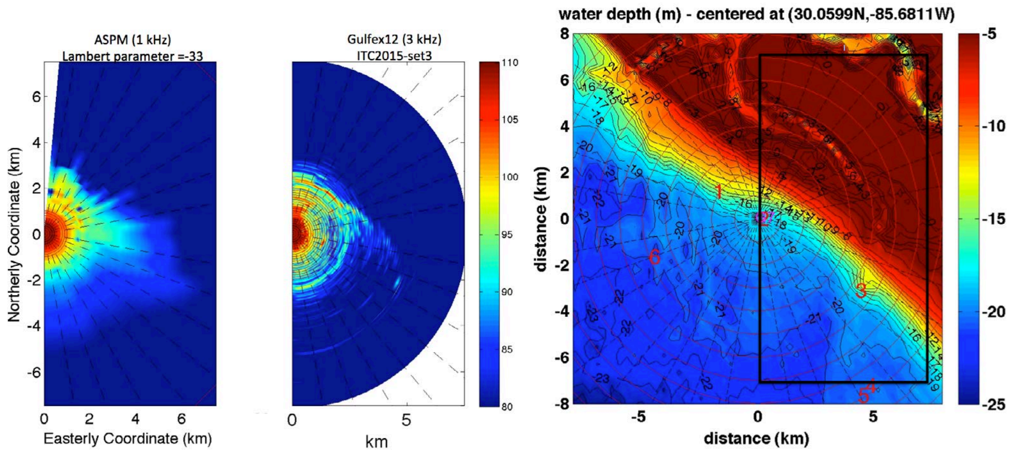

Figure 1. Left panel is ASPM 6.3 reverberation prediction, middle panel is measured reverberation, right panel is local topography of the experimental area. (Red regions of right panel are above sea level.)

Figure 2 shows the ASPM predicted reverberation wind speed dependence (ship wrecks in the area are also shown as point scatterers (clutter)). ASPM uses a modified Eckhart coherent reflection loss. Comparison of reverberation using coherent reflection loss models to reverberation using the energy loss model TOTLOSS being developed by Eric Thorsos and co-workers indicates ASPM wind speed dependence can be in error by several dB. This predicted inaccuracy will be tested as part of TREX13. ASPM 6.3 is a result of a significant effort (funded by ONR tech solutions) in code modernization. As a result we anticipate that better physics, such as TOTLOSS can be integrated into ASPM much easier than previously.

Targets-in-the-environment

Our efforts involve collaboration with NSWC PCD, the Sonar Group at TNO in the Netherlands and Washington State University (WSU). The Finite Element code development is led by TNO under ONRG contract. The technique allows one to examine symmetric targets but, as has been proven recently, allows one to examine those targets in situations where the target/environment geometry is not symmetric. The case examined in detail this year is for a target partially buried in sand at an angle (Figure 3 top/left). Acoustic color data taken during PONDEX09 (Figure 3 top/right-top) showed a splitting of the broadside return.

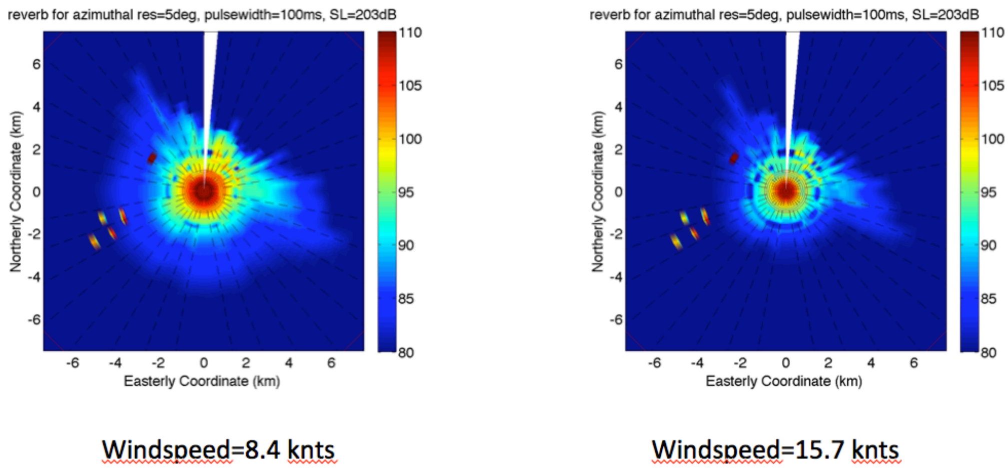

Figure 2. ASPM 6.3 predicted reverberation wind speed dependence.

The FE was able to recapture this splitting (Figure 3 top/right-bottom). In order to understand this splitting physically and study it experimentally we worked with WSU, developing a physical acoustics model and testing the model in the WSU tank. The FE model was implemented for the WSU conditions (Figure 3 bottom/left)with good agreement and then the physical acoustics model compared to FE (Figure 3 bottom/right). The physical acoustics model allows one to understand the reason for the angular split (ϕ) and predict its value ($\sin(\phi)=\tan(\theta_g)\tan(\theta_t)$) where θ_g is the grazing angle onto the sediment and θ_t is the angle of the target relative to the water/sediment interface. This type of predictive power might be obtainable via FE if parametric scans of parameters can be done. Doing full FE calculations over hundreds of conditions could take days, weeks or months. This has motivated integration of FE freefield models with physical acoustics approximations that allow TIER predictions 4 orders of magnitude faster than full FE.

This integration effort was spearheaded by Steve Kargl and paid for by SERDP funds. The speed of the calculation allows changes in TIER to be examined a function of geometry through development of movies of hypothetical parametric changes. Figure 4 shows frames from movies of an Aluminum UXO. The salient point is that the Rotation Angle/Frequency panels (i.e., acoustic color) in that figure indicate the radical differences in the acoustic color of the same simple target as a function of geometry. We now understand in detail the reason for the changes and the movies were essential to developing this understanding. In addition to using such movies to understand physics, the technique may offer computational advantages to mission planning tools under development by the Navy.

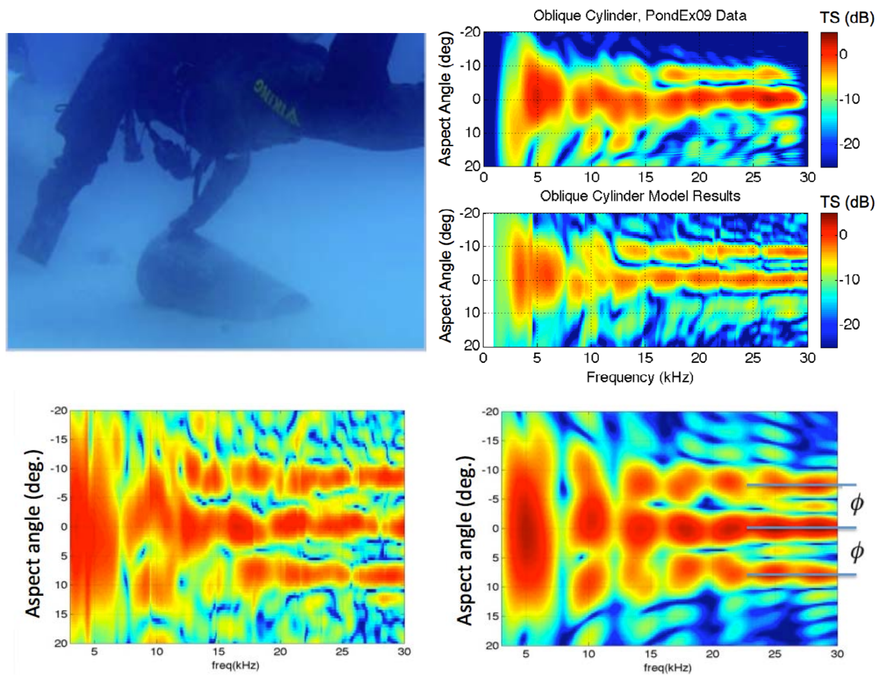

Figure 3. Examination of acoustic color for a target deployed at an angle to the water/send interface. Top panels show the experimental arrangement during PONDEX09 and data/FE comparison. The bottom panels show FE model results for a different oblique deployment (left) and the physical acoustics approximation (right).

Sediment Acoustics

The development of our understanding of sand acoustics over the last 30 years [2] included two major ONR-sponsored experiments SAX99 and SAX04 at high frequencies as well as many experiments at lower frequencies. In [3] many of the data (including SAX99 and SAX04) for sound speed and attenuation of sand as a function of frequency were summarized. As part of [2] we used that data in a final perspective on where sand acoustics knowledge stands. Figure 5 shows data/model comparisons as given in [2].

Our perspectives, developed in preparing the conference paper [2], are:

1. that a model of ocean sand as a porous medium with a rough interface and volume heterogeneity captures much of the experimental data,
2. we are at a point in the study of sand sound speed dispersion where better experiments are needed,
3. models that do not have the physics of relative grain/fluid motion incorporated in them are fundamentally flawed when applied to sand.

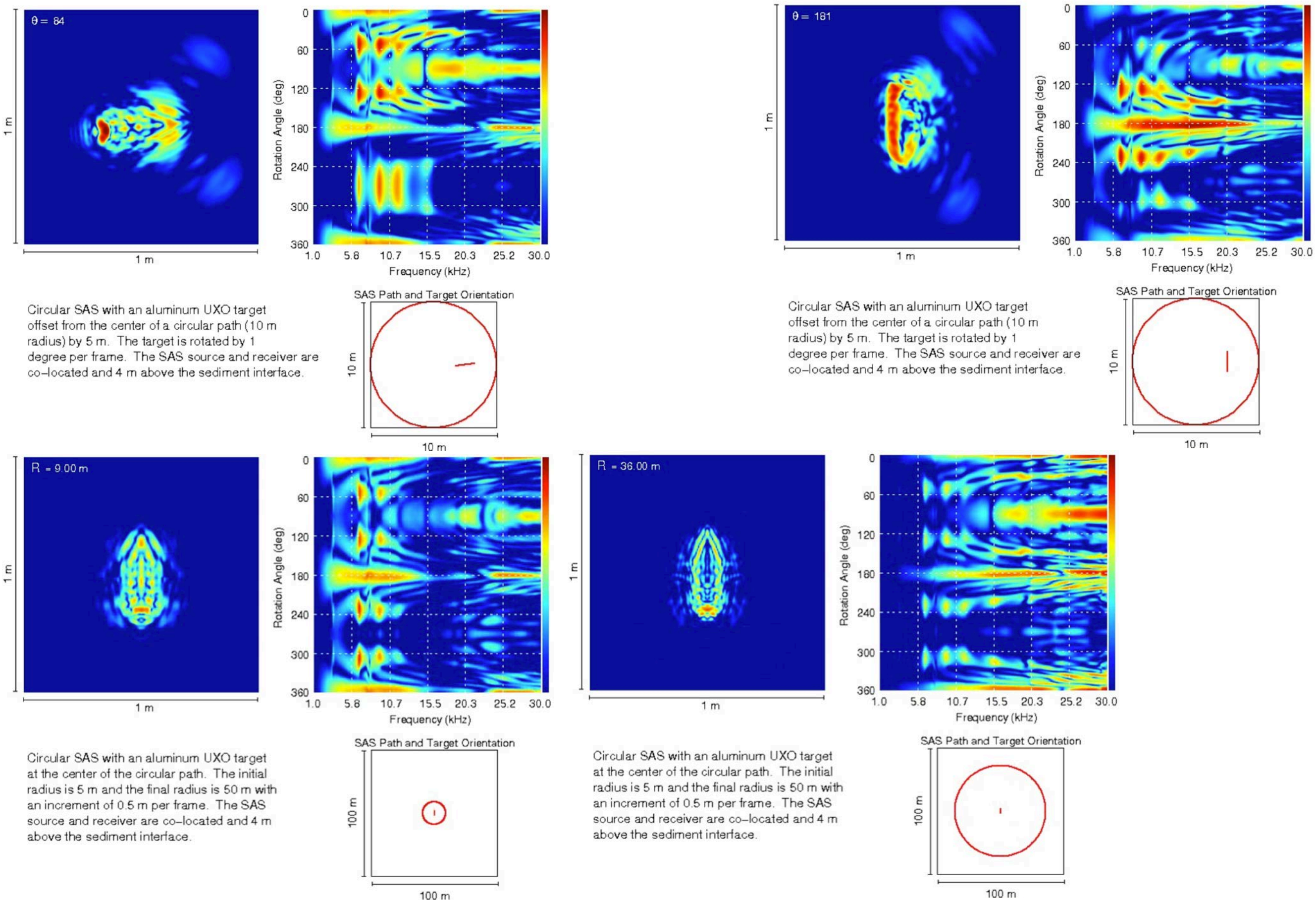

Figure 4. Frames from movies produced to understand TIER as a function of the sonar system range and angle to target. The target is an Aluminum UXO deployed proud on the bottom.

IMPACT/APPLICATIONS

Active ASW and MCM at mid-frequencies (1-10 kHz) is a mainstay of the US Navy. Modeling to predict Signal-to-Noise ratios and target signatures in the Ocean are thus of primary importance. The results of the modeling carried out and the experimental validation of these models can feed directly into the next generation of Navy models used in TDAs and mission planning tools.

RELATED PROJECTS

"Influence of Variation in Sediment Conditions on the Acoustic Response of Targets near the Sea Floor," ONR Grant N00014-10-1-0394, PI: A.L. Espana.

"High Fidelity Finite Element Modeling for the Identification of Low- to Mid-Frequency Proud and Buried Object Elastic Responses and SAS Image Features," ONR Grant #: N62909-10-1-7153, PI: M. Zampolli

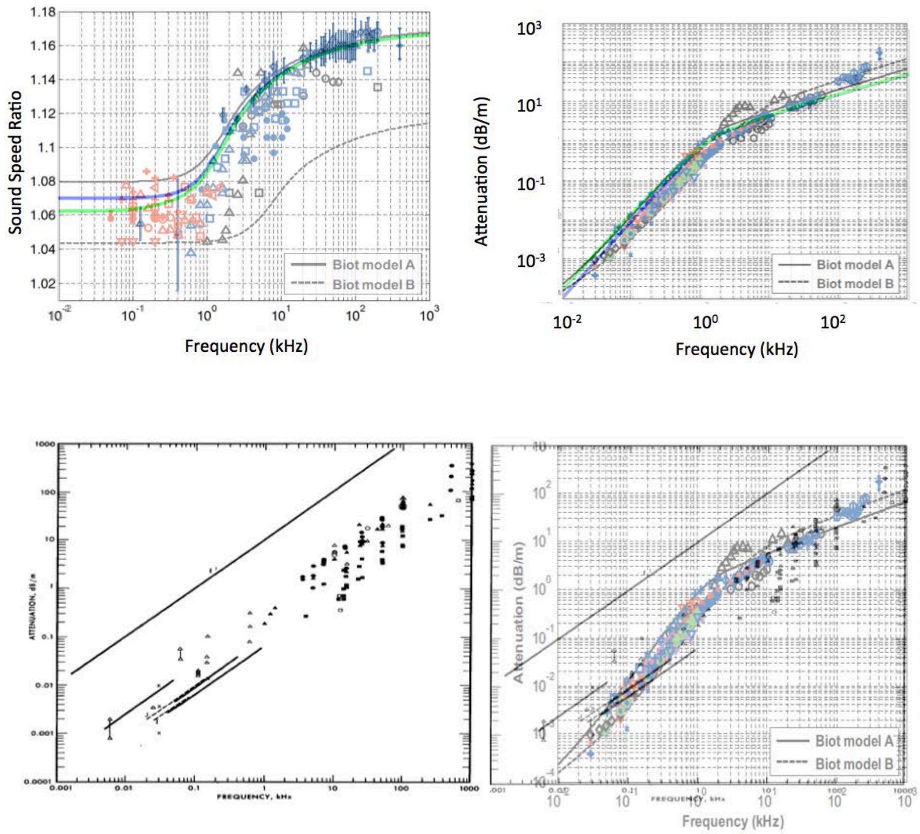

Figure 5. Top panels show data (1981-2009) summarized in [3] on sand sound speed and attenuation as symbols and two porous media type models discussed in [2] in blue (adiabatic model) and green (exchange of heat between fluid and grains at low frequencies). Bottom/left is summary of attenuation data to 1981. Bottom/right superposition of top/right and bottom/left indicating that data in the last 30 years indicates a non-linear frequency dependence of attenuation.

"Acoustic Color of mines and mine-like objects: Finite Element Modeling (FEM), Developing Automatic Target Recognition (ATR) strategies, and at-sea experimental validation," ONR Contract #: N00014-07-G-0557/0032, PI: K. L. Williams (APL-UW).

"Full Scale Measurement and Modeling of the Acoustic Response of Proud and Buried Munitions at Frequencies from 1-30 kHz," SERDP Contract #: W912HQ-09-C-0027, PI: S. G. Kargl

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[3] J. X. Zhou, X. Z. Zhang, and D. P. Knobles, “Low-frequency geoacoustic model for the effective properties of sandy seabottoms,” J. Acoust. Soc. Amer. 125, 2847–2866 (2009).

PUBLICATIONS

M. Zampolli, A. L. España, K. L. Williams, S. G. Kargl, E. I. Thorsos, J. L. Lopes, J. L. Kennedy, and P. L. Marston. “Low- to mid-frequency scattering from elastic objects on a sand sea floor: Simulation of frequency and aspect dependent structural echoes.” J. Comp. Acous., Vol. 20, No. 2 (2012).

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